Broadband Top-of-Atmosphere Fluxes from CERES

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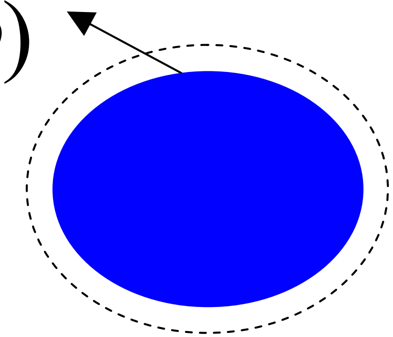
Instantaneous Fluxes at TOA and Angular Distribution Models

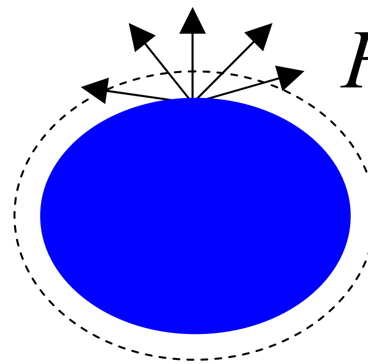
CERES Radiance Measurement

$$L(\theta_o, \theta, \phi)$$



$\Rightarrow$

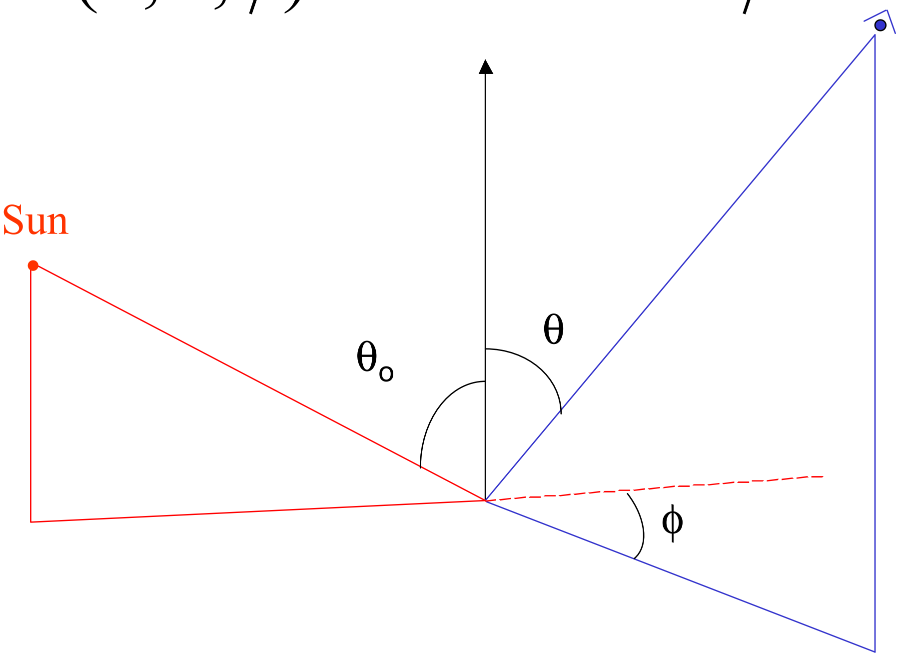
TOA Flux Estimate



$$F(\theta_o)$$

SW
LW
WN

$$F(\theta_o) = \int_0^{2\pi} \int_0^{\frac{\pi}{2}} L(\theta, \theta, \phi) \cos\theta \sin\theta d\theta d\phi$$



TOA flux estimate from CERES radiance:

$$\hat{F}(\theta_o,\theta,\phi)=\frac{\pi L(\theta_o,\theta,\phi)}{R_j(\theta_o,\theta,\phi)}$$

where,

$$R_j(\theta_o,\theta,\phi)=\frac{\pi L_j(\theta_o,\theta,\phi)}{\int_0^{2\pi}\int_0^{\frac{\pi}{2}} L_j(\theta_o,\theta,\phi)\cos\theta\ \sin\theta\ d\theta d\phi}$$

$R_j(\theta_o,\theta,\phi)$ is the Angular Distribution Model (ADM) for the "j^th" scene type.

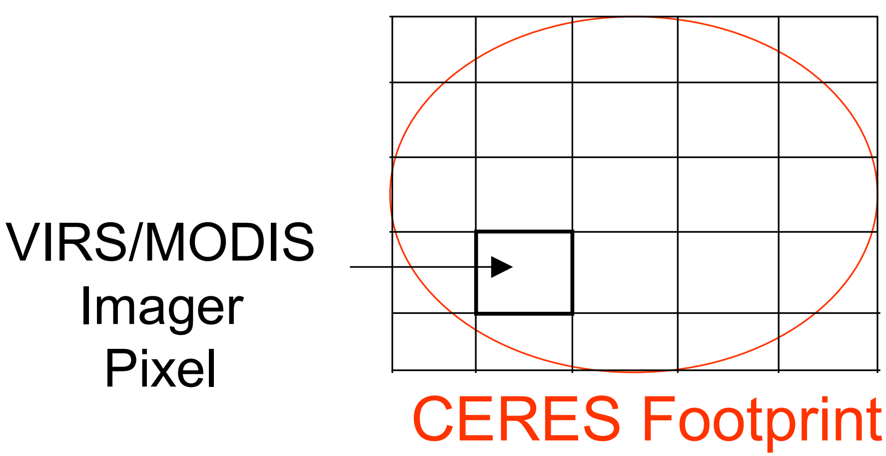
Anisotropic Model Scene Type Stratification

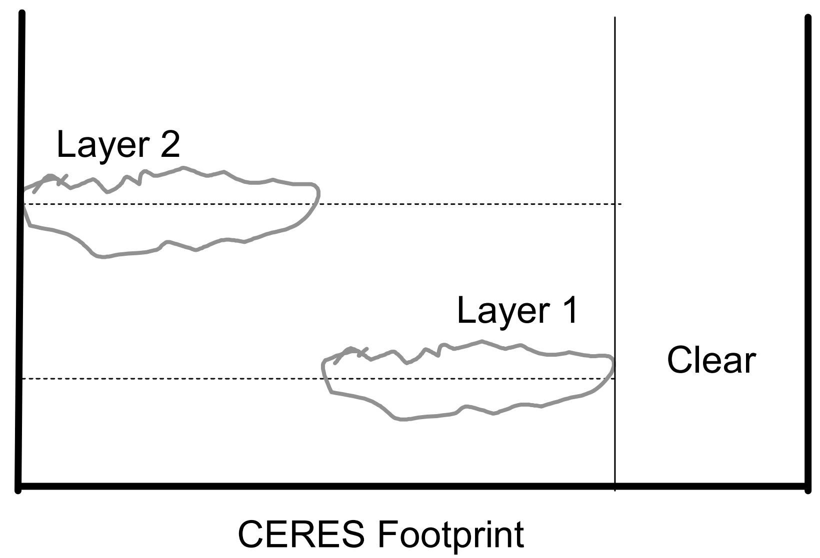
Spacecraft/Mission	Cloud	Surface Type	Total
TIROS 2, 3, 4	N/A	N/A	isotropy
TIROS 7 (Arking and Levine, 1967)	Global	Global	1
Nimbus 2, 3 (Rashke et al. 1973)	Cloud/Land	Ocean Snow	3
Nimbus-6, 7 (Taylor and Stowe, 1984; Jacobowitz et al., 1984)	All Cloud	Ocean Land Snow/Ice	4
ERBE (Smith et al., 1986; Suttles et al., 1988)	Clear Partly cloudy Mostly cloudy Overcast	Ocean Land Desert Snow Land-Ocean Mix	12

CERES Single Scanner Footprint (SSF) Product

- Coincident CERES radiances and imager-based cloud and aerosol properties.
- Use VIRS (TRMM) or MODIS (Terra, Aqua) to determine following parameters in up to 2 cloud layers over every CERES FOV:

Macrophysical: Fractional coverage, Height, Radiating Temperature, Pressure
Microphysical : Phase, Optical Depth, Particle Size, Water Path
Clear Area : Albedo, Skin Temperature, Aerosol optical depth, Emissivity





CERES/Terra Shortwave ADMs for Different Scene Types

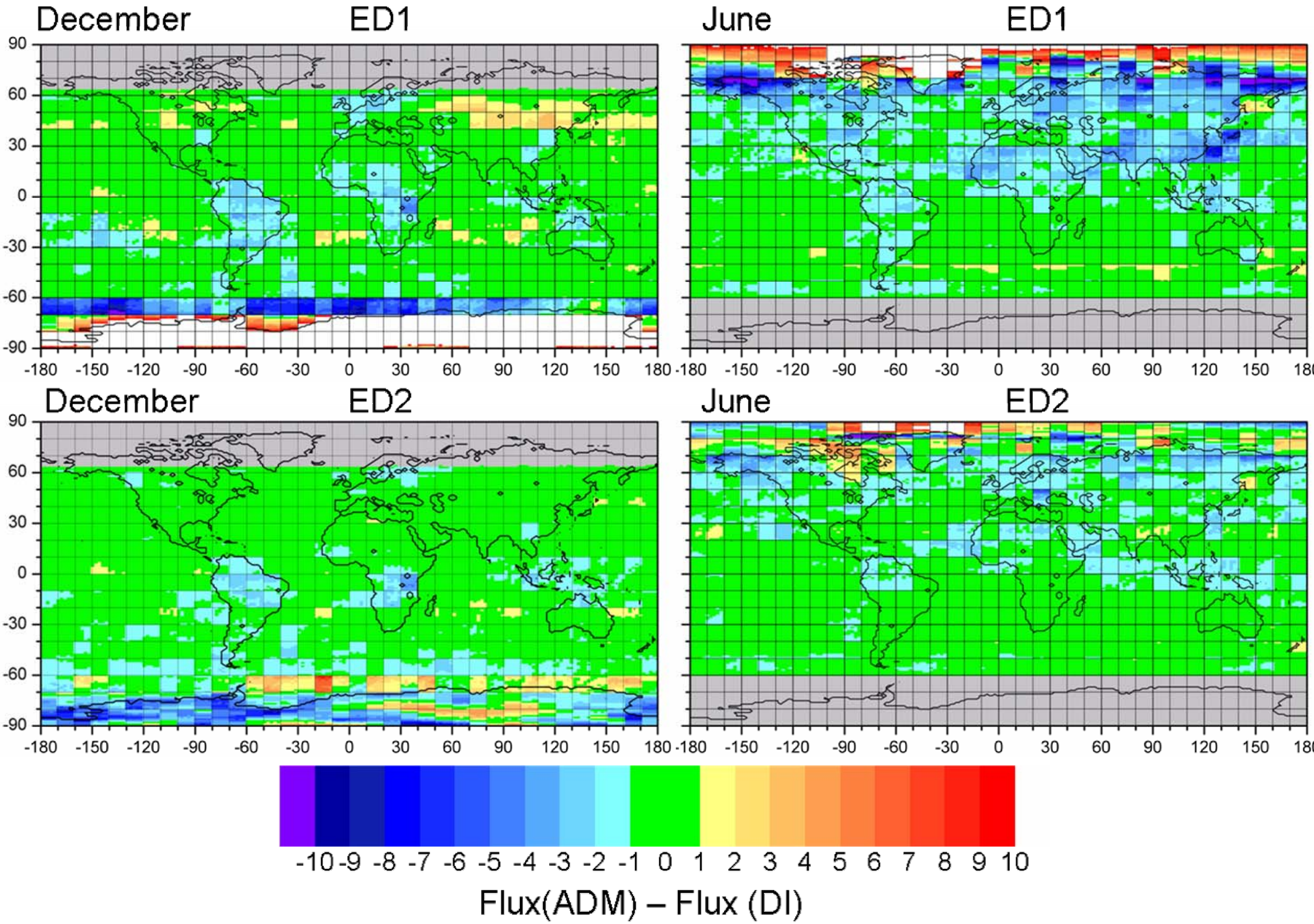
Scene Type	Description
Clear Ocean	Function of wind speed; Correction for aerosol optical depth included.
Cloud Ocean	Function of cloud phase; Continuous function of cloud fraction and cloud optical depth (5-parameter sigmoid).
Land & Desert Clear	1° regional monthly ADMs using Analytical Function of TOA BRDF (Ahmad and Deering, 1992).
Land & Desert Cloud	Function of cloud phase; continuous function of cloud cover and cloud optical depth; uses 1°-regional clear-sky BRDFs to account for background albedo.
Permanent Snow	Cloud Fraction, Surface Brightness, cloud optical depth
Fresh Snow	Cloud Fraction, Surface Brightness, Snow Fraction, cloud optical depth
Sea-Ice	Cloud Fraction, Surface Brightness, Ice Fraction, cloud optical depth

CERES/Terra Longwave & Window ADMs for Different Scene Types

Scene Type	Description
Clear Ocean, Land, Desert	Ocean, Forest, Cropland/Grass, Savanna, Bright Desert, Dark Desert, precip. water, lapse rate, skin temperature
Clouds Over Ocean, Land, Desert	Function of precip. water, skin temp., sfc-cloud temp. diff; continuous function of parameterization involving cloud fraction, cloud and sfc emissivity, sfc and cloud temp.
Permanent Snow Fresh Snow Sea-Ice	Each a function of cloud fraction, sfc temp, sfc-cld temp diff

Validation

SW Flux Direct Integration Test

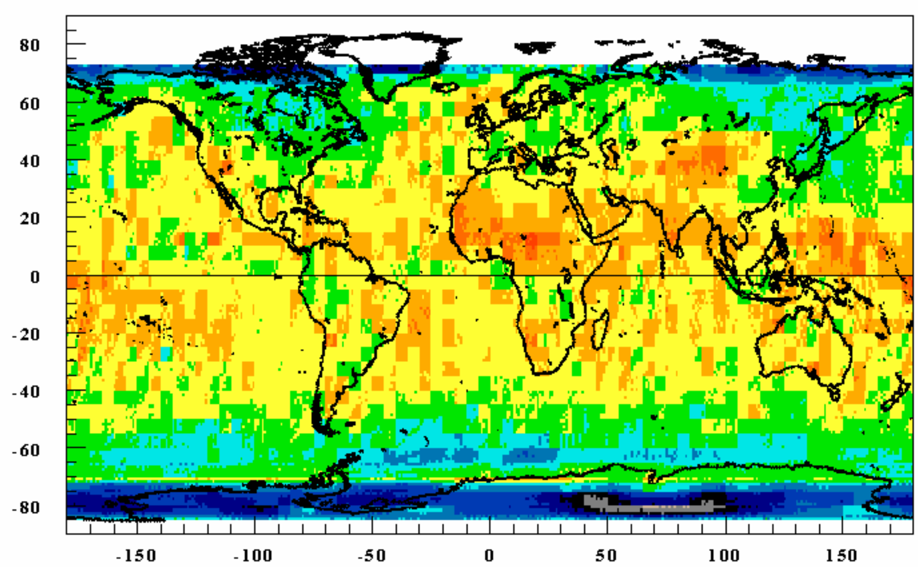


All-Sky **Daytime** Longwave Flux Direct Integration Tests (DJF)

TRMM ADMs
F(ADM) – F(DI)

MN DIFF
-0.13 W m^{-2}

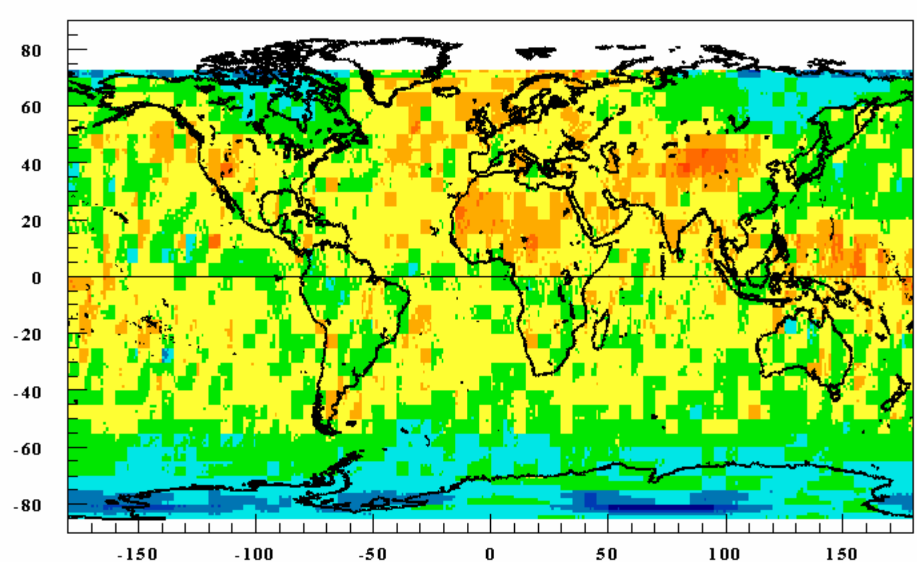
RMS Diff
1.45 W m^{-2}

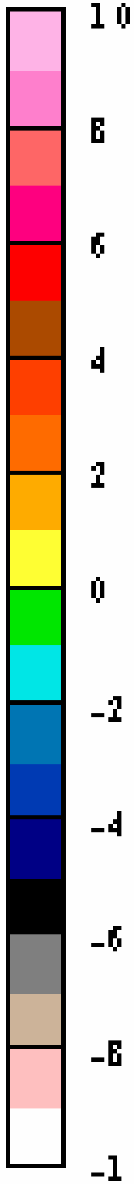


Terra ADMs
F(ADM) – F(DI)

MN DIFF
-0.04 W m^{-2}

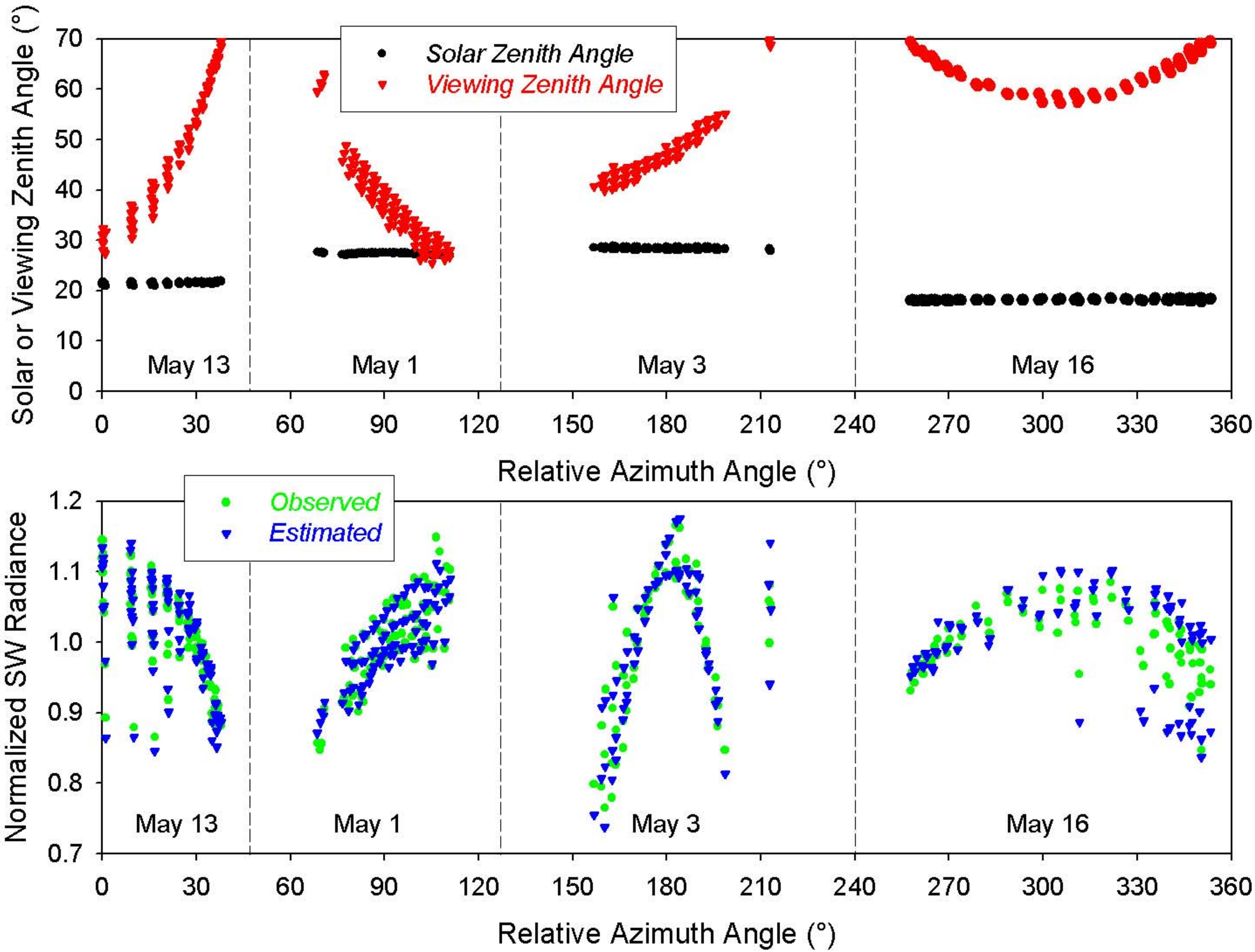
RMS Diff
0.93 W m^{-2}



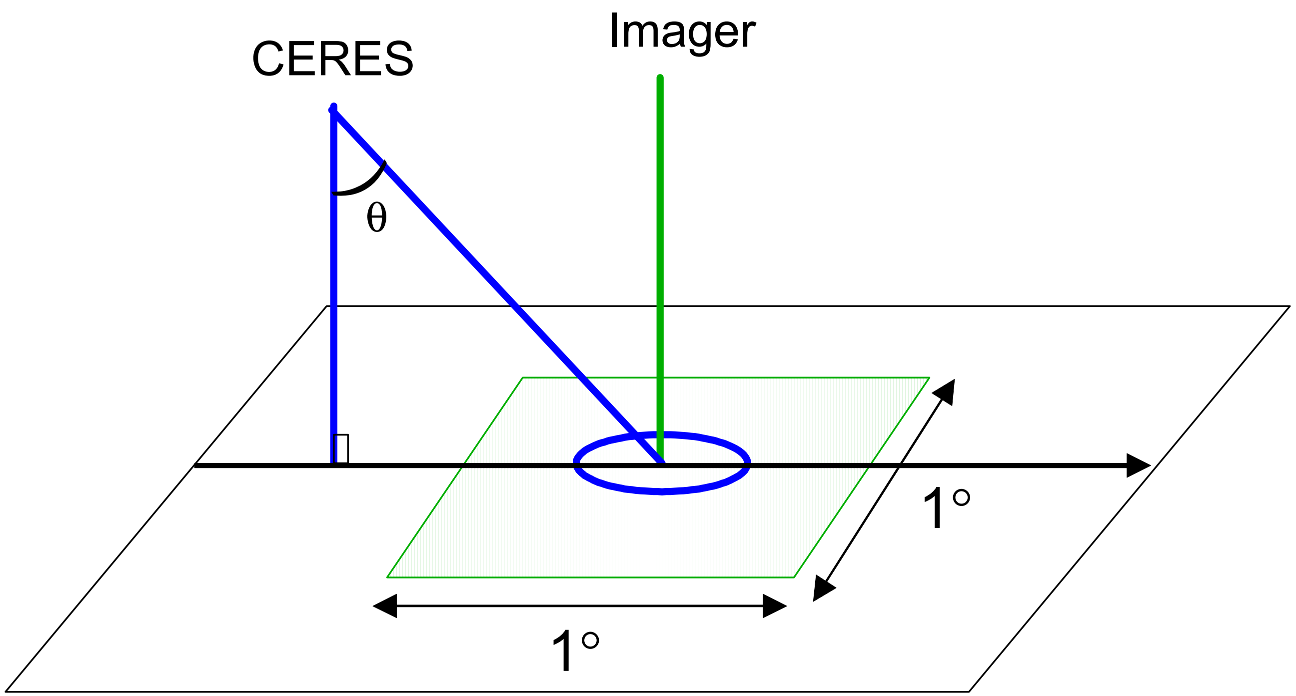


Flux Error
(W m^{-2})

Observed and ADM Anisotropy Over ARM SGP-Overcast

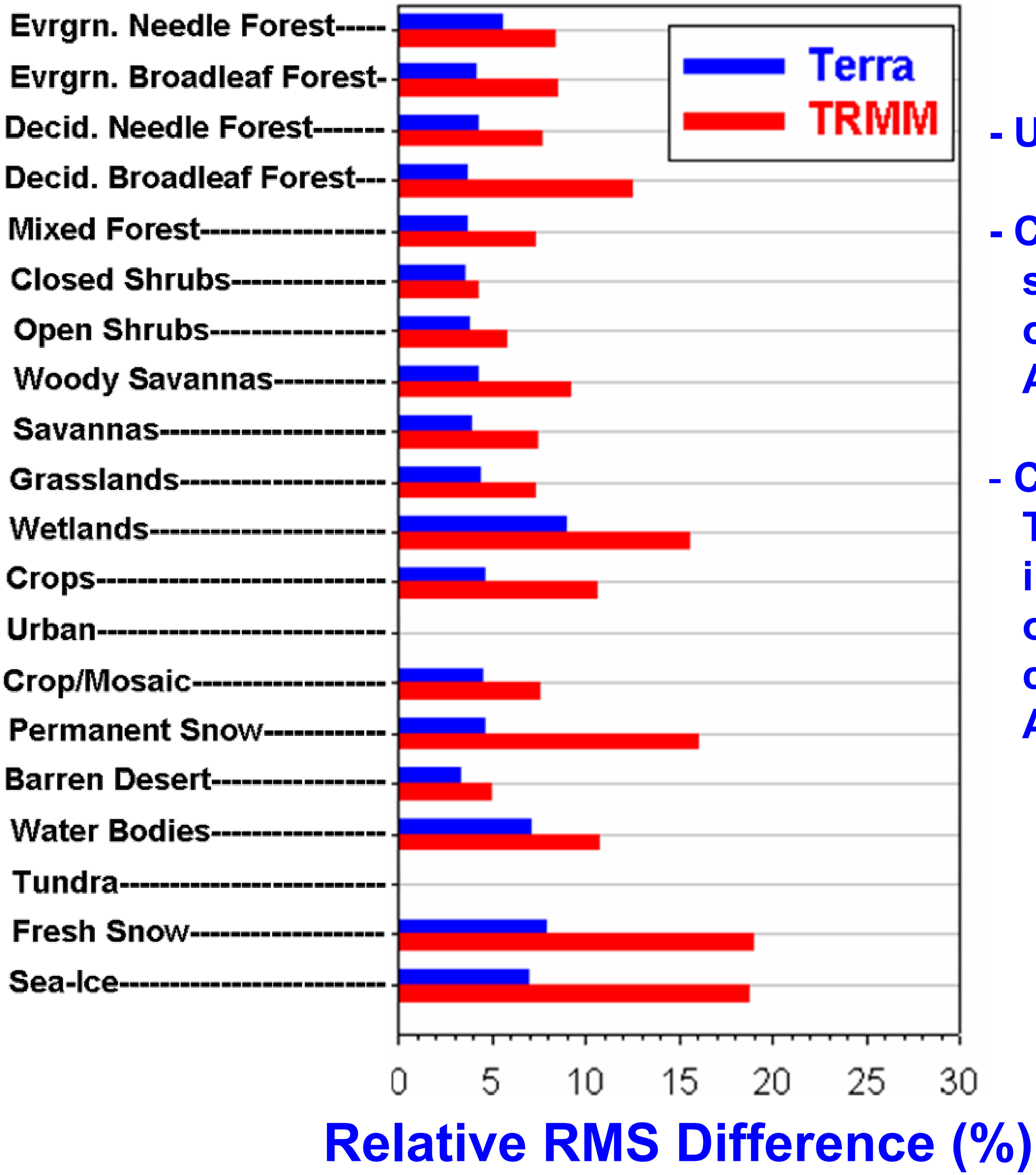


Instantaneous TOA Flux Consistency Tests



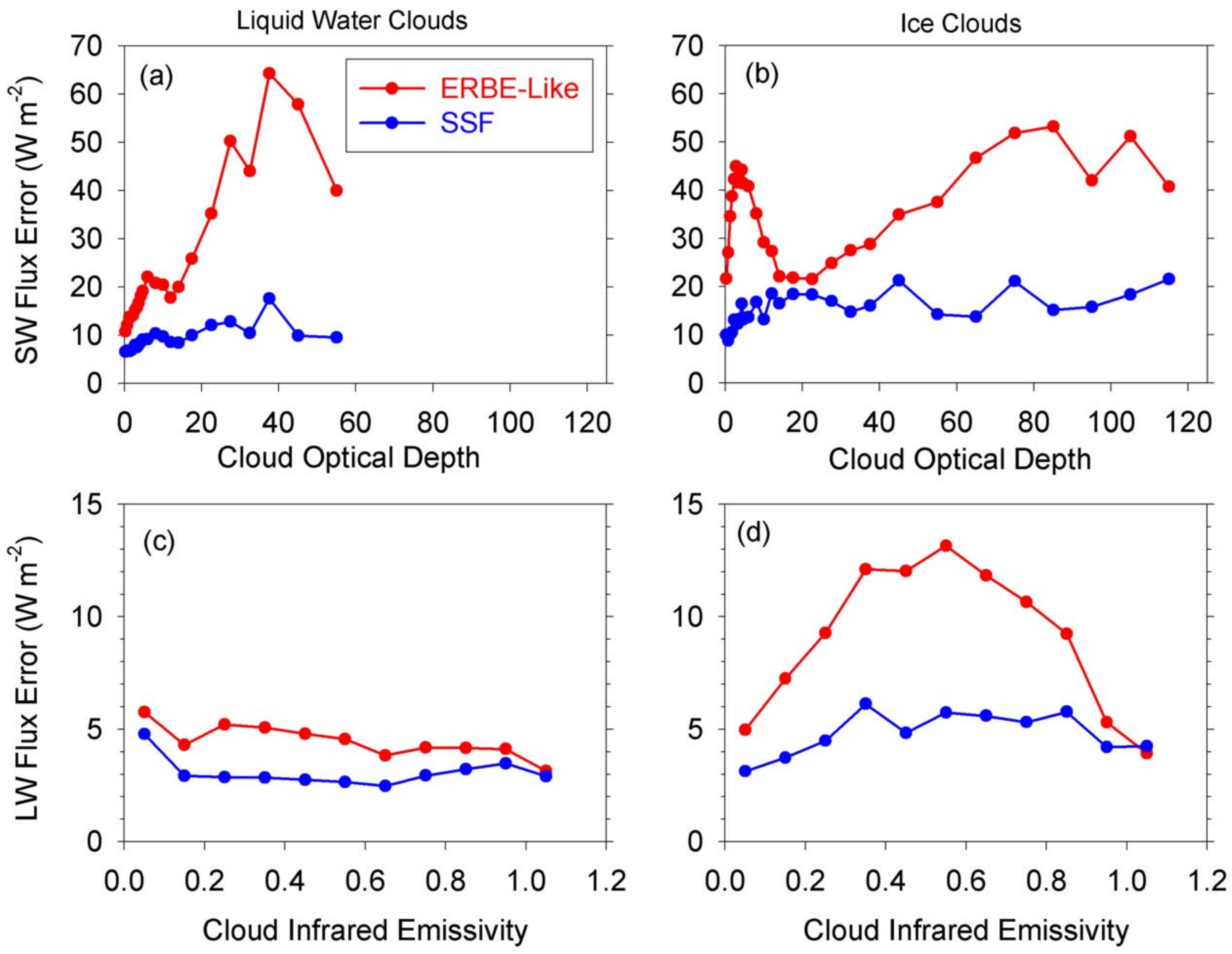
- Convert imager nadir visible radiance to broadband flux
- Compare off-nadir CERES flux with nadir flux inferred from imager visible radiance
- 41 global alongtrack days over 2 years

Clear-Sky Multiangle Consistency Test [SW Flux (θ=50-60) – SW Flux (Nadir)]



- Use CERES in alongtrack mode
- Compare TOA fluxes from the same scene observed at oblique and nadir view angles. Are they consistent?
- Clear-sky fluxes from new CERES Terra ADMs show a factor of 2-3 improvement in consistency over forest, snow and sea-ice compared to CERES TRMM ADMs.

Instantaneous TOA Flux Error by Cloud Property



Instantaneous **SW** TOA Flux Consistency
($F(\theta=50°-60°) – F(Nadir)$)

Clear-Sky

Region	Mean SW Flux ($W\ m^{-2}$)	Bias (%)	RMS (%)	No. FOVs
Tropics	223.3	0.6	3.7	32,352
Midlat	163.1	0.5	4.9	15,117
Polar	293.0	-2.0	6.5	19,105

All-Sky

Region	Mean SW Flux ($W\ m^{-2}$)	Bias (%)	RMS (%)	No. FOVs
Tropics	282.6	0.8	8.6	202,639
Midlat	347.4	0.7	6.3	394,018
Polar	292.0	-1.9	9.0	172,998

Instantaneous **LW** TOA Flux Consistency
(F(θ=50°-60°) – F(Nadir))

Clear-Sky

Region	Mean LW Flux ($W\ m^{-2}$)	Bias (%)	RMS (%)	No. FOVs
Tropics	307.3	-1.1	1.8	38,830
Midlat	285.5	-0.9	1.7	23,929
Polar	204.1	-0.8	2.7	17,520

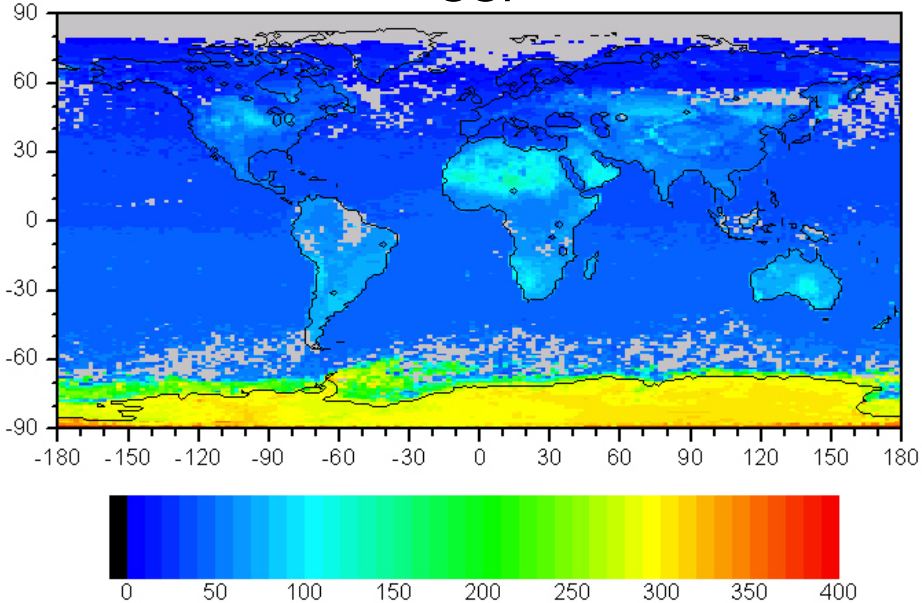
All-Sky

Region	Mean LW Flux ($W\ m^{-2}$)	Bias (%)	RMS (%)	No. FOVs
Tropics	282.2	-0.8	3.0	266,246
Midlat	234.3	-0.9	3.8	340,387
Polar	200.5	-0.6	3.3	147,239

Cloud Radiative Forcing:
ERBE vs CERES

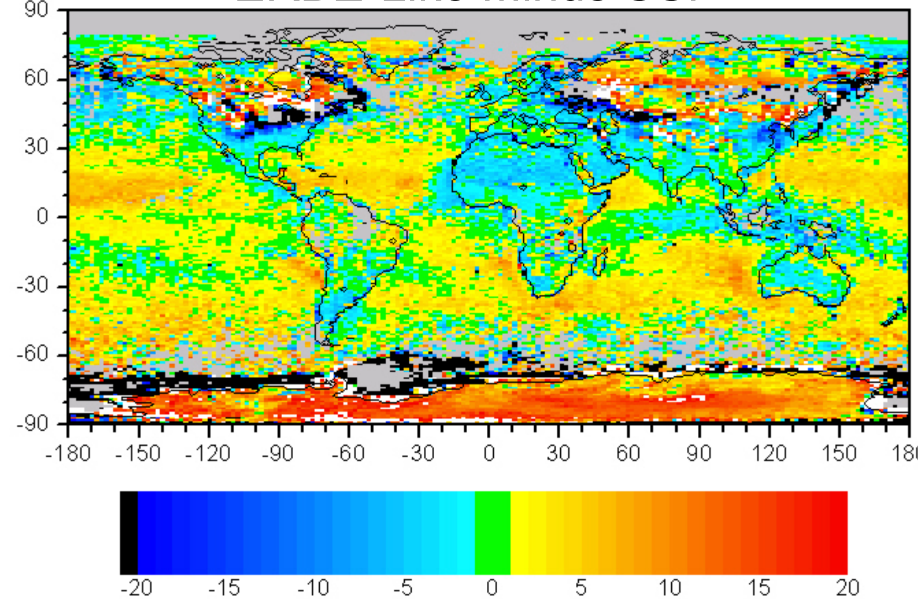
CERES ERBE-Like and SSF SW TOA Flux: Clear-Sky (DJF 2000-2001)

SSF

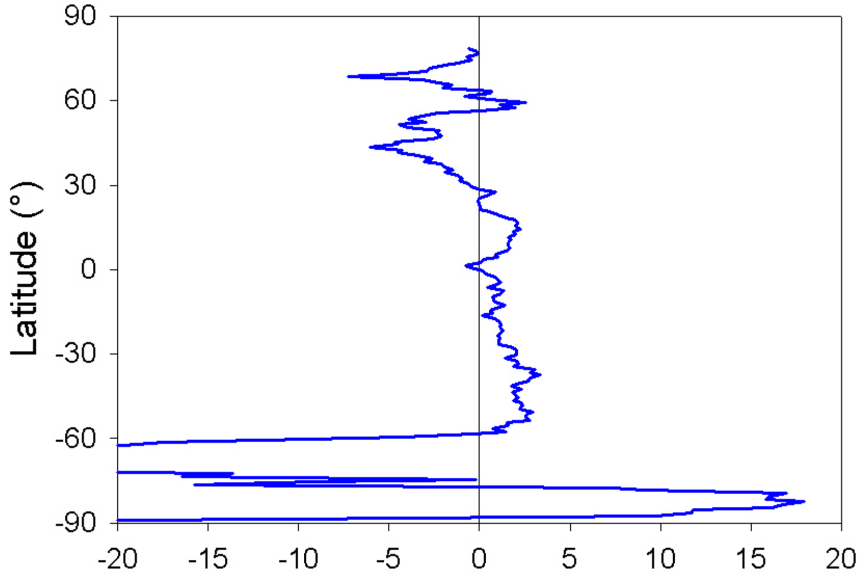


SW Flux (W m^{-2})

ERBE-Like Minus SSF

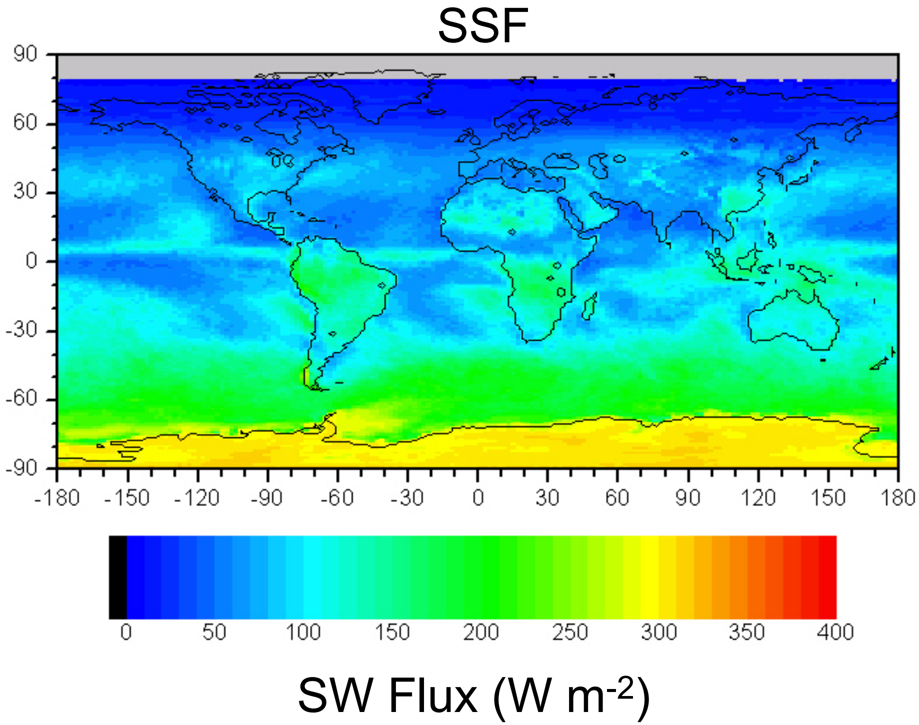


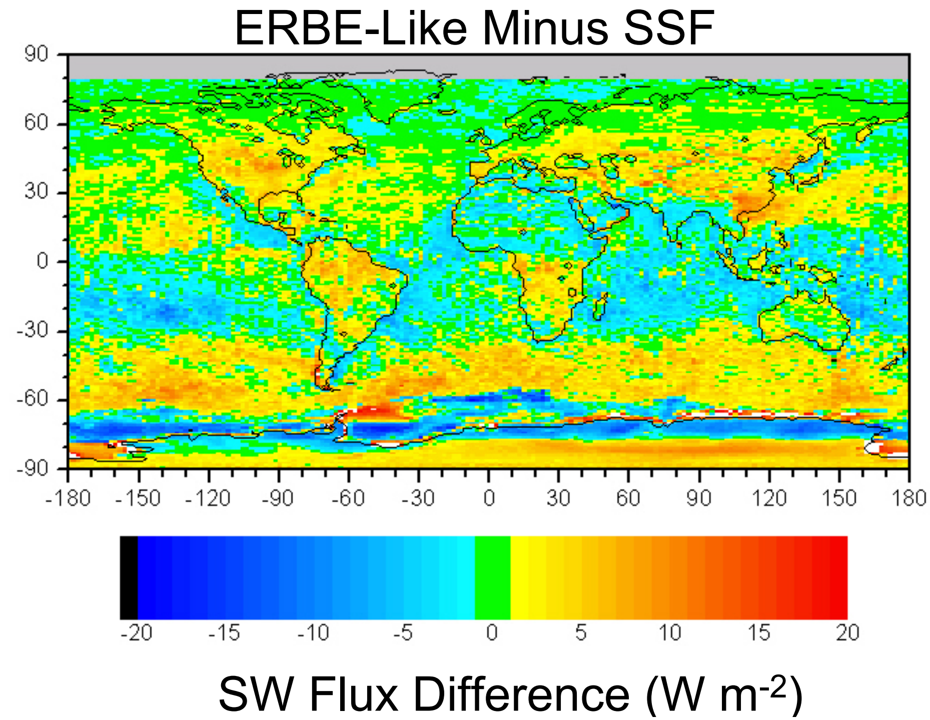
SW Flux Difference (W m^{-2})



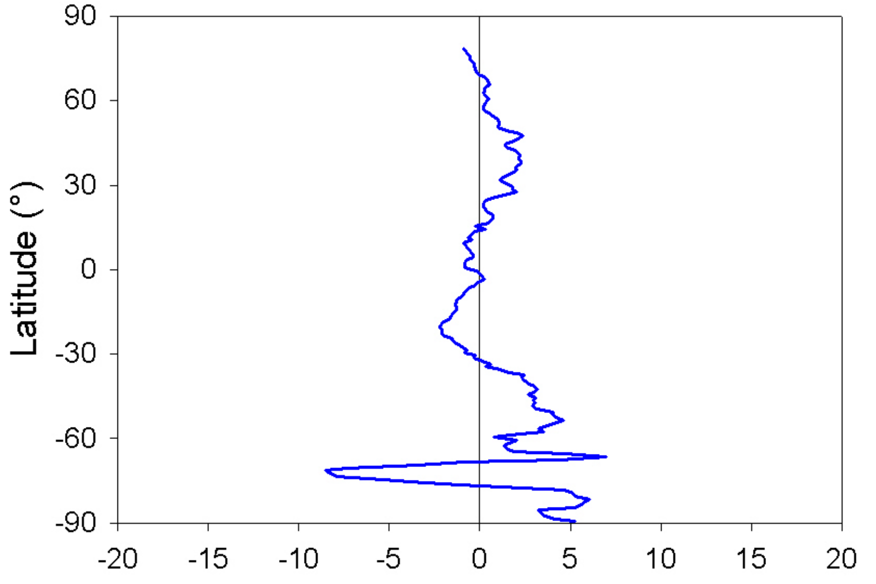
Global Difference: -1.1 W m-2

CERES ERBE-Like and SSF SW TOA Flux: All-Sky (DJF 2000-2001)



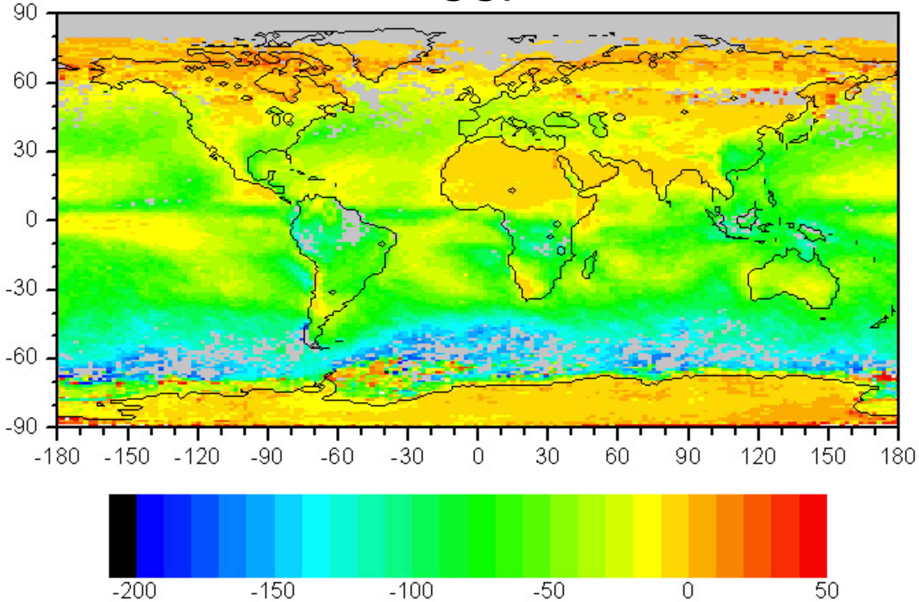


Global Difference: 0.49 W m^{-2}



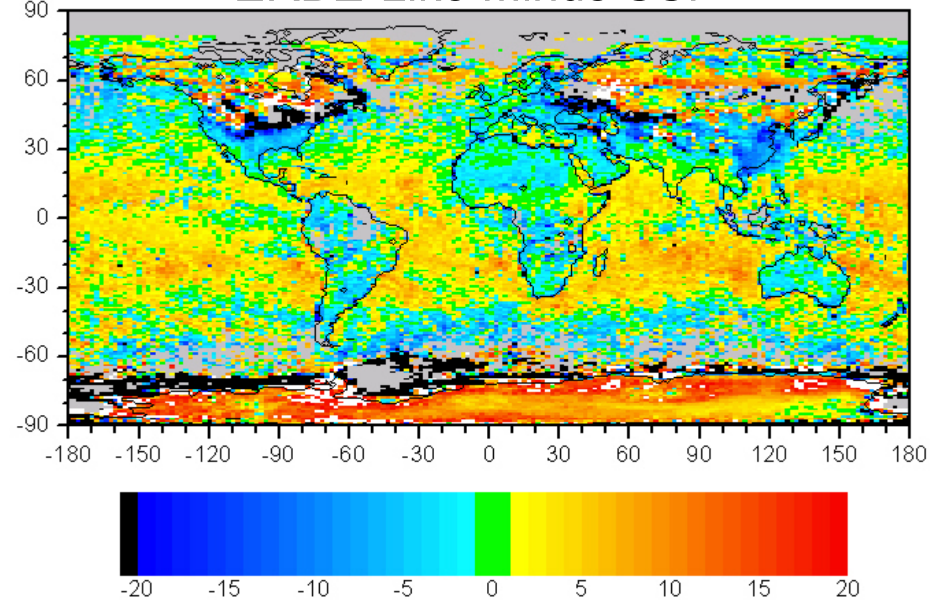
CERES ERBE-Like and SSF SW Cloud Forcing (DJF 2000-2001)

SSF

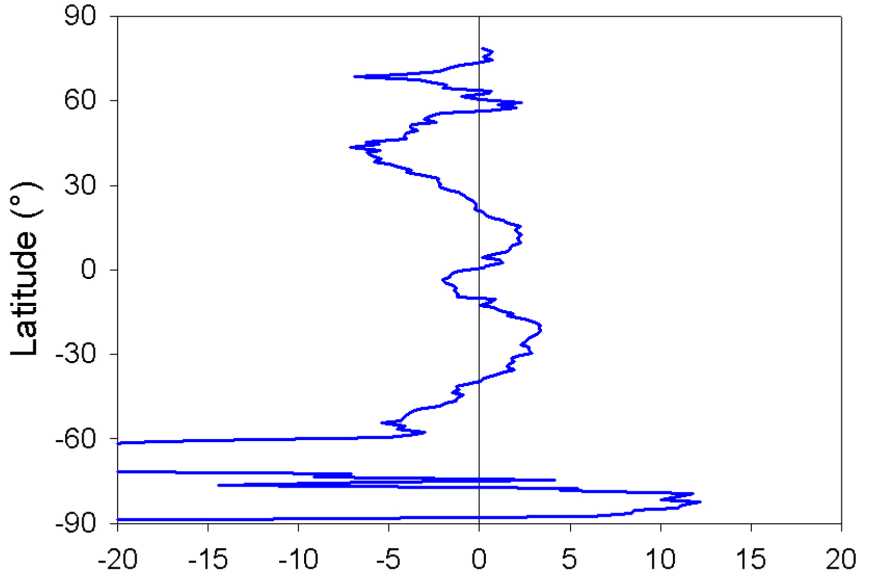


SW CRF (W m^{-2})

ERBE-Like Minus SSF

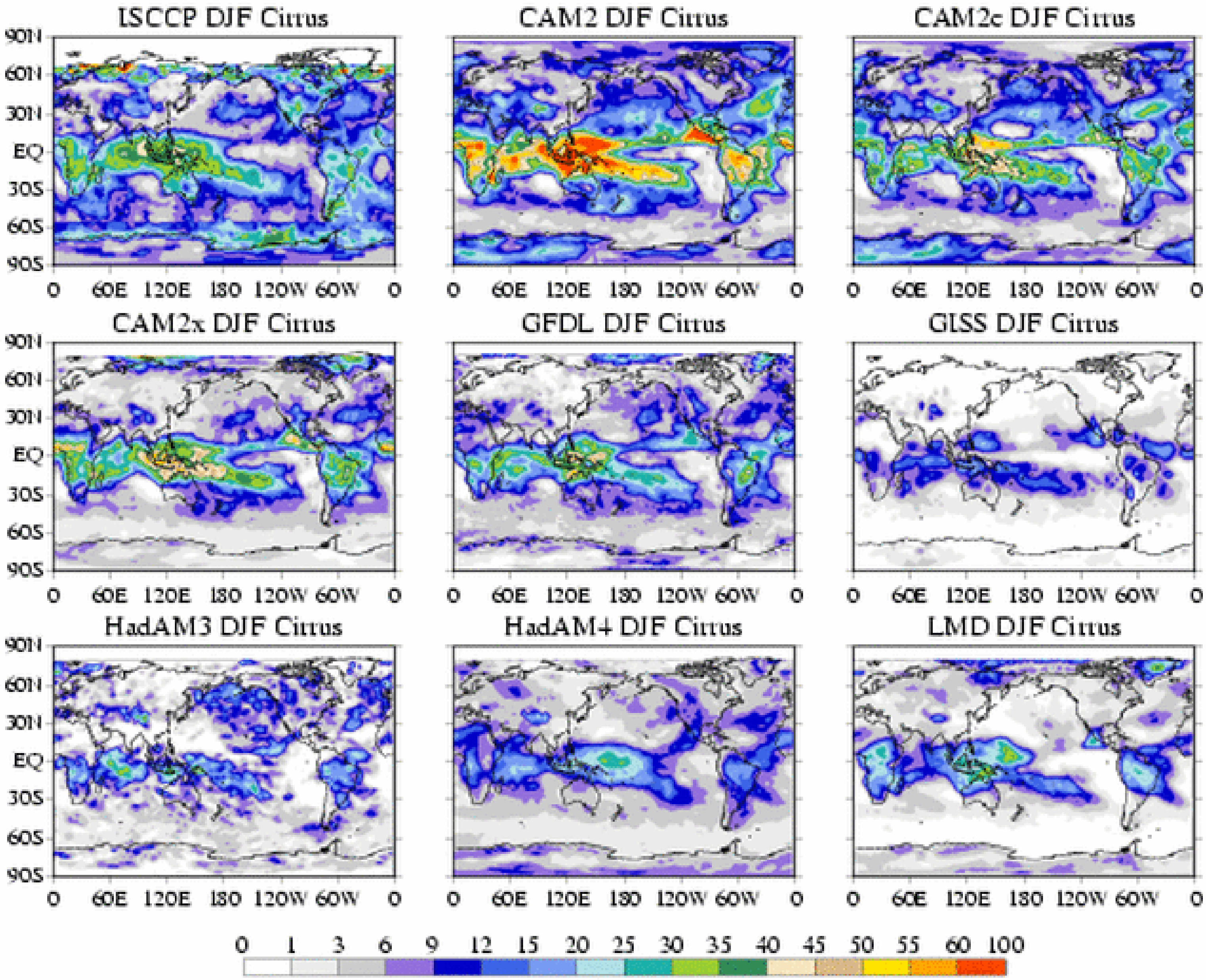


SW CRF Difference (W m^{-2})



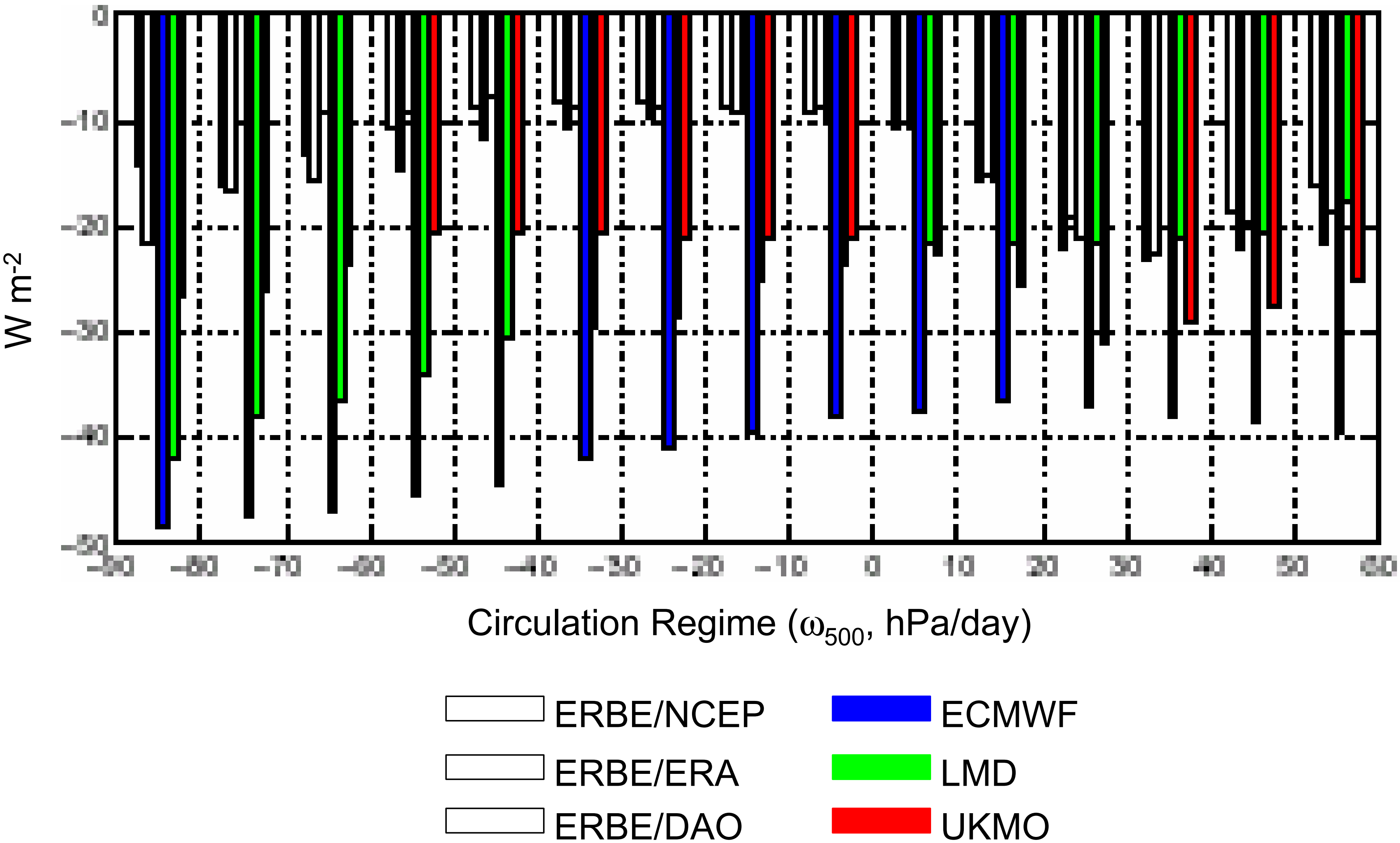
Global Difference: -1.93 W m-2

Model vs Obs Comparisons


ISCCP DJF Cirrus
CAM2 DJF Cirrus
CAM2c DJF Cirrus
CAM2x DJF Cirrus
GFDL DJF Cirrus
GISS DJF Cirrus
HadAM3 DJF Cirrus
HadAM4 DJF Cirrus
LMD DJF Cirrus
90N 60N 30N EQ 30S 60S 90S
0 60E 120E 180 120W 60W 0
0 1 3 6 9 12 15 20 25 30 35 40 45 50 55 60 100

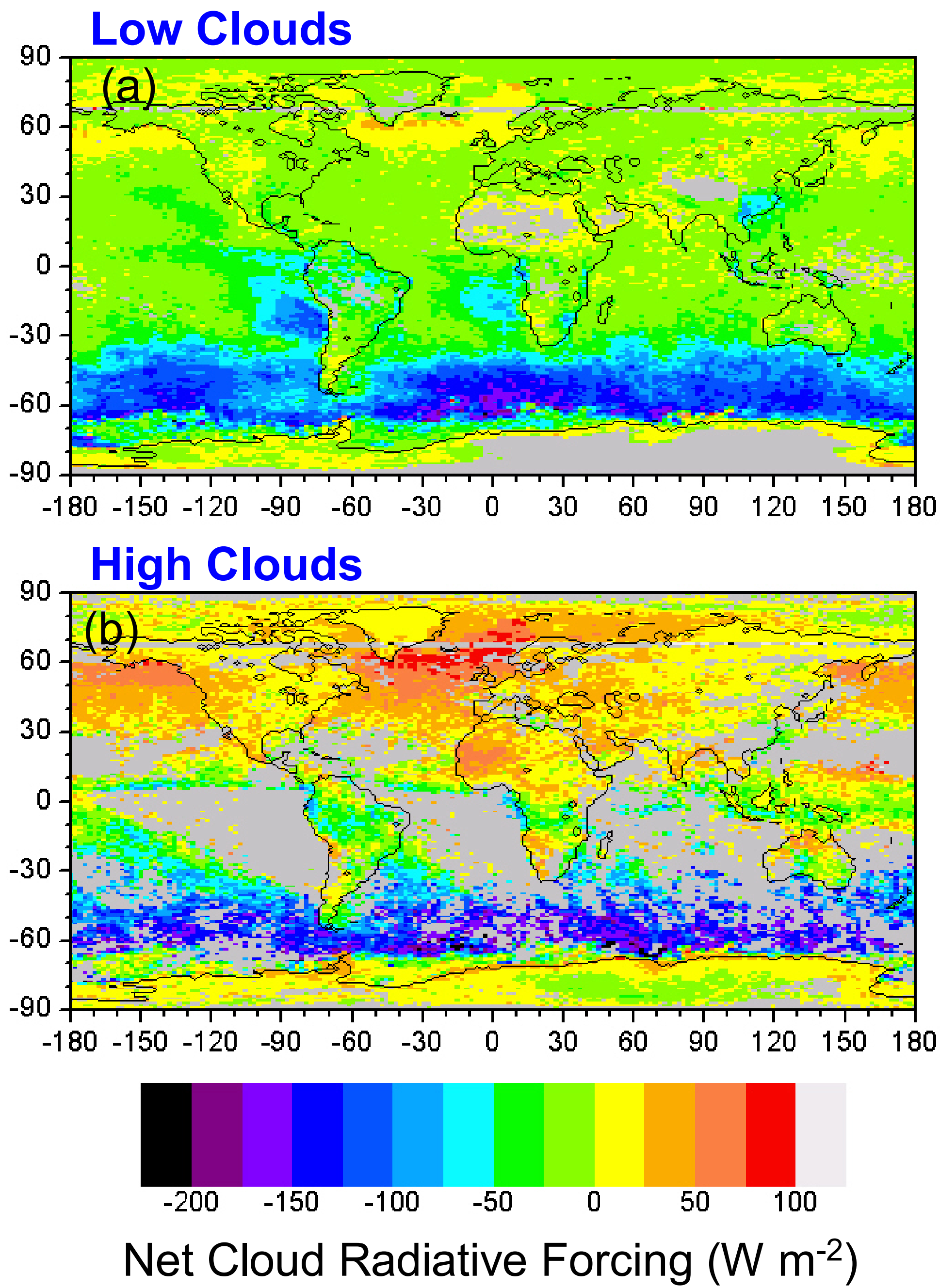
M. Zhang

Net Cloud Radiative Forcing in Different Dynamical Regimes as Defined by Monthly Mean 500 hPa vertical velocity



From S. Bony et al. (2003)

Net Cloud Radiative Forcing by Cloud Type (December 2001)



Summary

- CERES merges data from MODIS, CERES and GMAO to produce self-consistent aerosol-cloud-radiation data products.

- These data have been used to develop new Angular Distribution Models (ADMs) based on 2 years of CERES Terra measurements.

- CERES TOA flux uncertainties from new CERES ADMs:
  - => Regional mean TOA flux : < 1 W m^{-2}
  - => Instantaneous SW TOA flux : 10 -15 W m^{-2}
  - => Instantaneous LW TOA flux : 5 -10 W m^{-2}

- New CERES ADMs show notable improvements in TOA flux accuracy relative to ERBE, particularly for specific cloud types.

- Large regional differences between ERBE and CERES SW cloud radiative forcing at high latitudes, tropical ocean and land.